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Characterizing Meadow Vegetation With Multitemporal Landsat Thematic Mapper Remote Sensing

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Abstract

Wet meadows are important biological components in the Blue Mountains of eastern Oregon. Many meadows in the Blue Mountains and elsewhere in the Western United States are in a state of change owing to grazing, mining, logging, road development, and other factors. This project evaluated the utility of remotely sensed data to characterize and monitor meadow vegetation for 32 meadows in the Wallowa-Whitman and Umatilla National Forests. The meadows had been previously classified into different plant community types based on the occurrence of specific indicator species of sedge (*Carex* spp). We analyzed the spectral signature of the sample meadows by using the Kauth-Thomas (tasseled-cap) transformation calculated for a temporal series of five Landsat thematic mapper (TM) images. The Landsat TM images were obtained for monthly intervals from April to September in 2000. We found that the sequence of Landsat TM scenes provided ample resolution to differentiate most of the plant communities examined. A larger sample size and additional field verification of the meadow vegetation data would have provided a more definitive evaluation of the methods. The multitemporal approach holds promise for monitoring change in wetland indicator species like the sedges, and for rapid characterization of grass, grasslike, and herbaceous vegetation over large areas. The technique also may be useful to detect the current location and spread of plants, especially those with distinctive vegetative or floral phenologies.

Keywords: Meadows, *Carex*, Landsat, multitemporal, sedge.

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Introduction

Wet meadows are important biological components in the Blue Mountains of eastern Oregon. They support high levels of plant and animal diversity and are home to many rare and endemic plant and animal species (Crowe and Clausnitzer 1997). Meadows are highly valued for their scenic and recreational qualities and are an important component of wildlife and amphibian habitat. They also serve as ground-water reservoirs, feeding mountain streams that are spawning and rearing habitat for threatened and endangered salmonids.

Vegetation in many meadows in the Blue Mountains has undergone significant change owing to disturbances like grazing, mining, logging, road development, and other practices (Crowe and Clausnitzer 1997, Kaufman and Krueger 1984). These disturbances often result in downcutting of streams that pass through the meadows, triggering long-term changes in meadow vegetation and interdependent hydrologic function. Depth to ground water is a major determinant of meadow vegetation, especially shallow-rooted species of sedges and grasses (Otting 1998). When ground water is lowered and obligate wetland plant species are displaced, the belowground biomass and soil water-holding capacity of the meadow is reduced as well (Otting 1998). This in turn diminishes the capability of the meadow to provide cool subsurface water during summer, which is crucial to the maintenance of aquatic habitat for federally listed species like chinook salmon (*Oncorhynchus tshawytscha* Walbaum) and bull trout (*Salvelinus confluentus* Suckley).

Meadow restoration is currently a high priority for the USDA Forest Service and other federal land management agencies (Crowe and Clausnitzer 1997). Meadow characterization is an important component of this process and is essential for designing site-specific restoration projects. A useful tool in this regard would be the development of remote sensing methods that aid in differentiating between sedge species that are sensitive to seasonal patterns of soil moisture vs. those that are not. The plant species of most interest are the sedges (*Carex* spp.) that have well-known preferences for seasonal patterns of soil moisture (Crowe and Clausnitzer 1997). In addition, the presence or absence of specific sedge species can be an indicator of overgrazing or other disturbances (Crowe and Clausnitzer 1997, Otting 1998).

A number of previous studies have demonstrated the utility of using remotely sensed data for vegetation classification work for rangelands (e.g., Clark et al. 2001, Tueller 1989) and forests (e.g., Franklin et al. 2000, Townsend and Walsh 2001). However, previous work has focused on the detection of relatively coarse vegetation categories, and to our knowledge, there are no studies that have attempted to distinguish among individual plant communities that are defined by their composition of forbs, grass, or grasslike species (Crowe and Clausnitzer 1997) with the use of

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remotely sensed data. The objective of this project was to test the utility of remotely sensed data to aid land managers in the identification and characterization of meadows primarily dominated by sedge species in the Blue Mountains.

Methods

The meadows included in this study are located in the Blue Mountains between Heppner and La Grande, Oregon, on the Umatilla and Wallowa-Whitman National Forests (figs. 1 and 2). The meadows represented a variety of vegetative types and moisture conditions and were located at elevations between 3,150 and 5,500 feet. A number of meadows were known to have experienced overgrazing and other

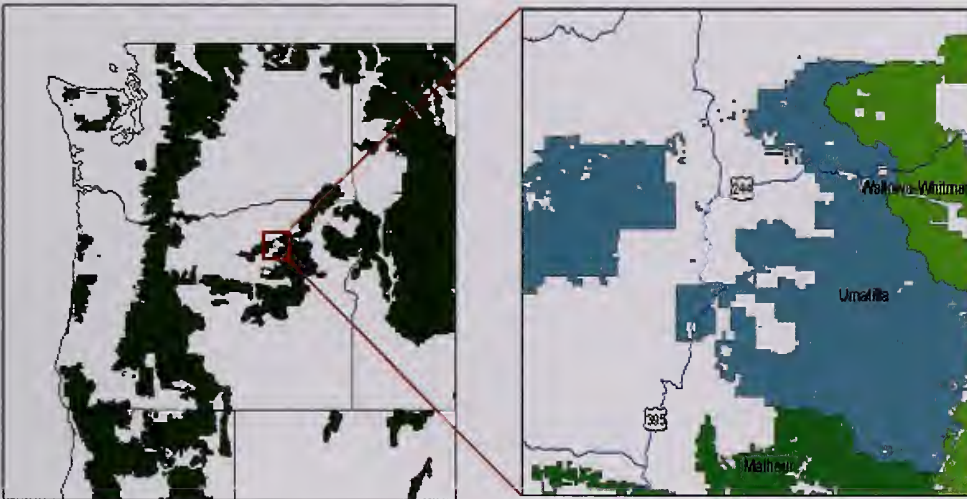


Figure 1—General location on the Umatilla and Wallowa-Whitman National Forests of meadows studied.



Figure 2—Desolation Meadow at the headwaters of Desolation Creek, North Fork John Day Ranger District, Umatilla National Forest, is typical of the meadows included in the study.

practices that led to changes in vegetative composition over the past 20 or more years. In all, 32 meadows were included in the study, 22 of which were part of the riparian classification work of Crowe and Clausnitzer (1997). The remaining meadows were typed as part of the Umatilla National Forest vegetation inventory. Meadows were chosen based on minimum size (>2 ha) and the absence of intermittent shrub or forest vegetation. The meadows were digitized by using digital ortho photos from 1998 as a backdrop. Boundaries were digitized approximately 15 m inside the meadow edge to eliminate the influence of adjacent, nonwetland areas. Although initial analyses were performed with all five dates of imagery (see below), the June and August dates were dropped for the cluster analyses owing to clouds obscuring several key meadows.

Five scenes of enhanced thematic mapper (TM) imagery (30 by 30 m) acquired throughout the 2000 growing season were used for the project. The five acquisition dates for the imagery were April 9, June 16, July 2, August 3, and September 20. The data were obtained from the U.S. Geological Survey EROS Data Center. The TM imagery was georeferenced and corrected for terrain. The images were checked for accurate coregistration and were found to be within one pixel of each other. The imagery was processed by using ERDAS® Imagine 8.5.²

The tasseled-cap (Kauth-Thomas) transformation (Crist and Cicone 1984, Crist and Kauth 1986, Kauth and Thomas 1976) was applied to each image, transforming the Landsat TM data with predefined coefficients into three new components related to scene brightness, greenness, and moisture content (fig. 3). The brightness component is a weighted average of all the bands. The greenness component weights most heavily the near-infrared radiation (IR) and red bands and is an indicator of photosynthetic activity. Moisture content component is related to soil moisture status, and weights the mid-IR bands most heavily (fig. 3).

Zonal means of tasseled-cap derived brightness, greenness, and moisture values were calculated for each meadow. Initial examination of these values revealed distinct seasonal patterns between meadows (fig. 4). Seasonal greenness and moisture “signatures” were identified and appeared to correspond well with different plant compositions and their seasonal patterns of spring green-up and fall senescence.

Tasseled-cap values (brightness, greenness, and moisture) of 32 meadows for three dates of imagery were analyzed with a principal components analysis (PCA) by using SAS software (SAS Institute 1997). Plots of PCA scores were examined to

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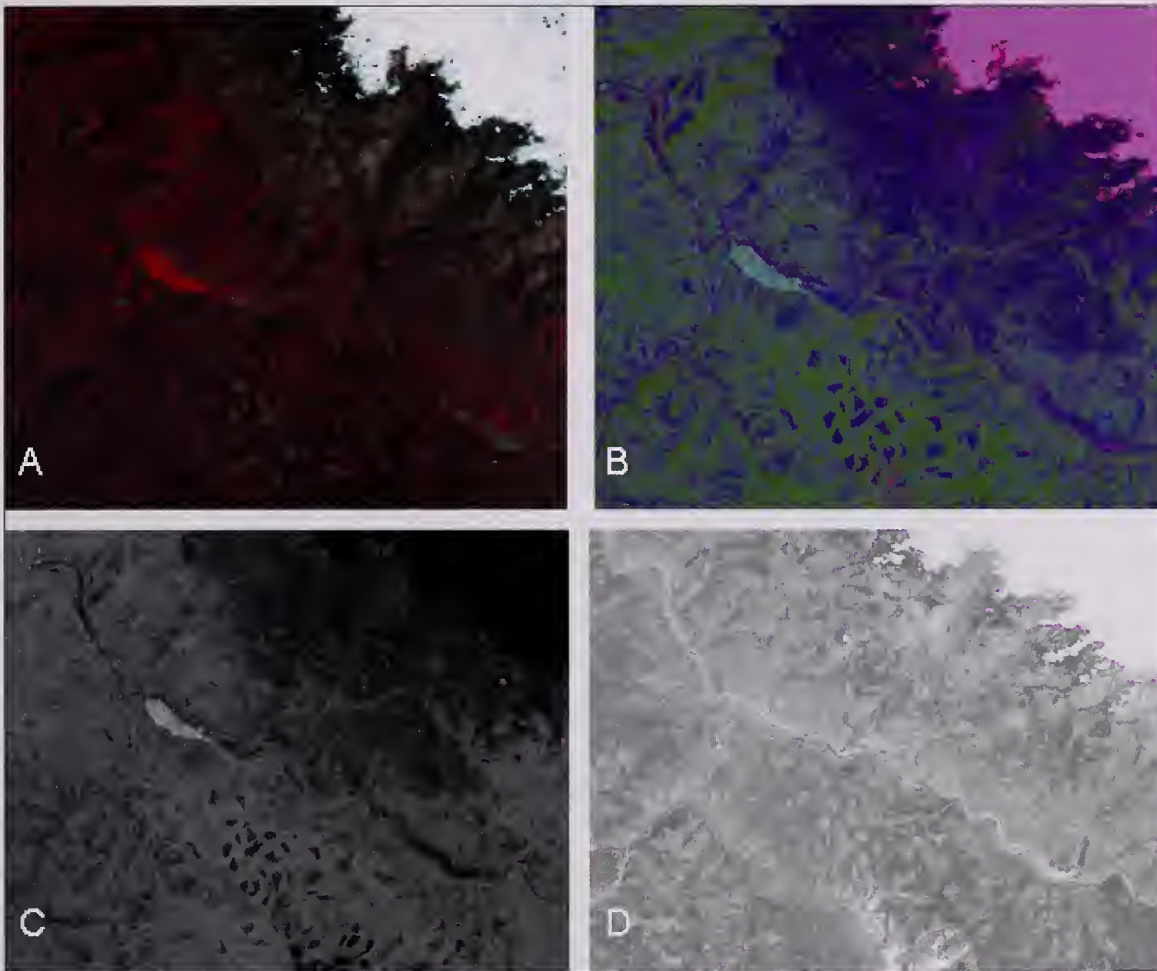


Figure 3—Tasseled-cap-derived images of (A) original color-infrared image (note the snow in the upper right corner, the river running diagonally, and the harvested patches); (B) color composite of brightness, greenness, and moisture content; (C) greenness in gray scale; (D) moisture content (soil moisture) in gray scale (note lighter shades of gray indicate higher amounts of greenness and wetness).

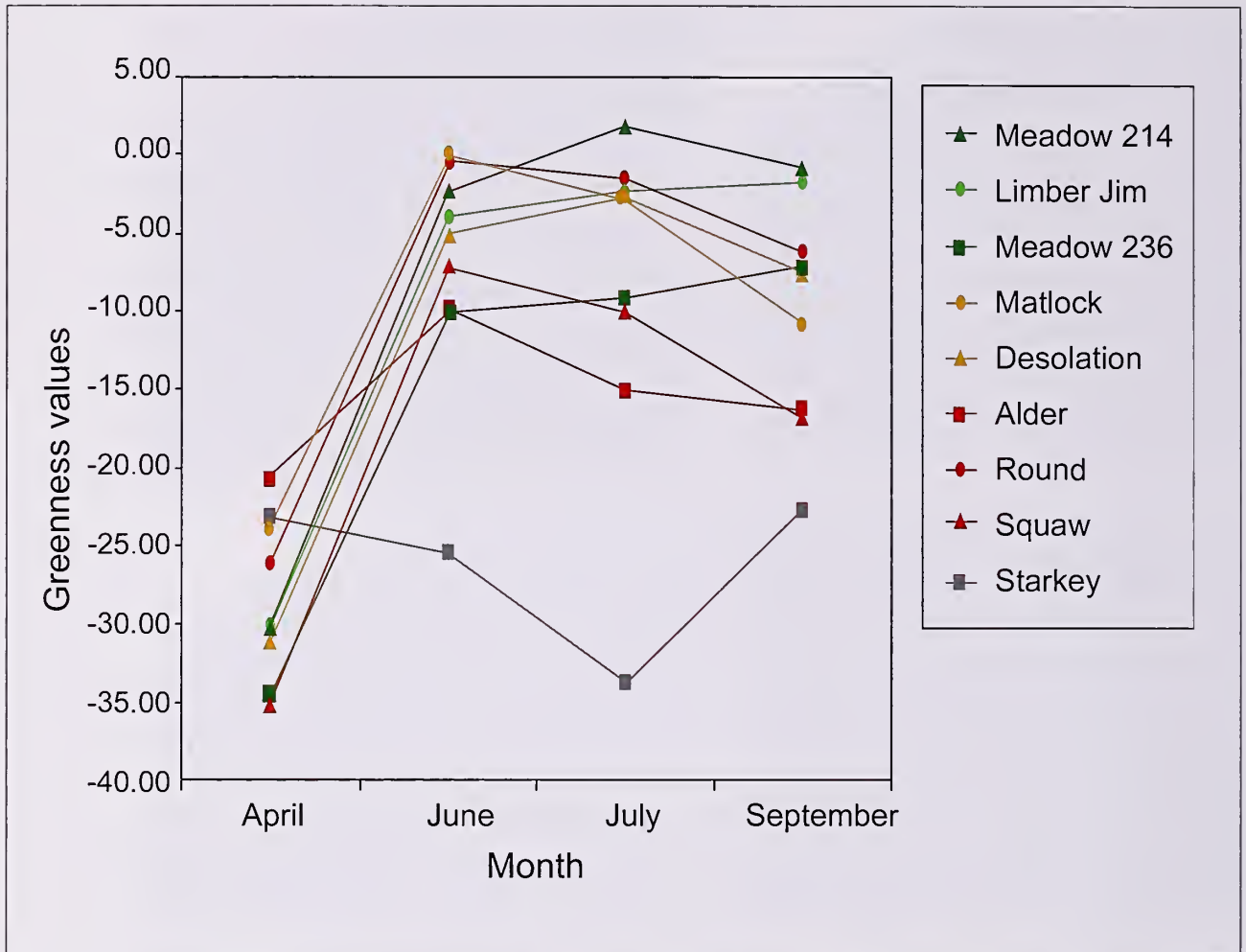


Figure 4—Greenness plots of nine samples demonstrate the potential of using tasseled-cap indicators for characterizing meadows. Meadows 214, 236, and Limber Jim are dominated by hydrophytic sedge species, indicators of wet conditions throughout summer (high and increased levels of greenness at the end of the season). Matlock and Desolation Meadows are dominated by tufted hairgrass, an indicator of drier conditions (decrease in greenness values late in season). Alder, Round, and Squaw Meadows also showed a decrease in values late in summer from drying out. Starkey is a dry bunchgrass grassland.

determine relationships among the meadows. Ideally, similar meadows (with similar plant associations and seasonal hydrological patterns) will fall into clusters in the PCA plots. The small number of meadows included in the study precluded using a more formal supervised classification.

Results

The first three principal components explained 81 percent of the total variation of the three tasseled-cap indices for the sample meadows. Variable loadings for the principal components were complex and difficult to interpret. Principal component analysis 1 (PCA1) loaded heavily for the negative late-season greenness. Principal component analysis 2 (PCA2) loaded high for greenness in all seasons and negative moisture in the late season. A plot of PCA1 versus PCA2 scores showed clusters of meadows that in many, but not all, cases corresponded to specific plant associations. Overall, the PCA performed relatively well in terms of differentiating plant meadows (fig. 5), especially considering that most of the meadows contain other sedge species as minor components of the vegetation.

The group of dry upland bunchgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith. [AGSP]) sample sites formed a cluster with high scores for PCA1 and low scores for PCA2. These grasslands were included to examine the signature of dry upland communities relative to the remaining sample. The slightly moister fescue grassland (*Festuca idahoensis* Elmer [FEID]) also showed a slightly higher score for PCA2, providing a clear contrast among upland meadows with different moisture levels.

The meadows with higher scores for PCA2 were primarily CANE (*Carex nebrascensis* Dewey) and DECA (*Deschampsia cespitosa* (L.) Beauv.). The CANE meadows typed out with the highest combined scores, although one DECA meadow and one CAAQ (*C. aquatilis* Wahl.) meadow were intermingled. Data from both of these meadows have not been field validated, and it is likely that the DECA meadow is not typed correctly.³ *Carex nebrascensis* is a specific indicator for overgrazed meadows. Most of the DECA meadows form a large cluster (fig. 5) with moderate to high PCA2 scores.

The plant associations dominated by the two most hydrophytic species, CAAQ and CAUT (*C. utriculata* Stokes), were not well represented in the sample. In the case of CAAQ, some differences in PCA scores for the two meadows were

³ Riley, S. 2003. Personal communication. Botanist, Umatilla NF, 2517 SW Hailey Ave., Pendleton, OR 97801.

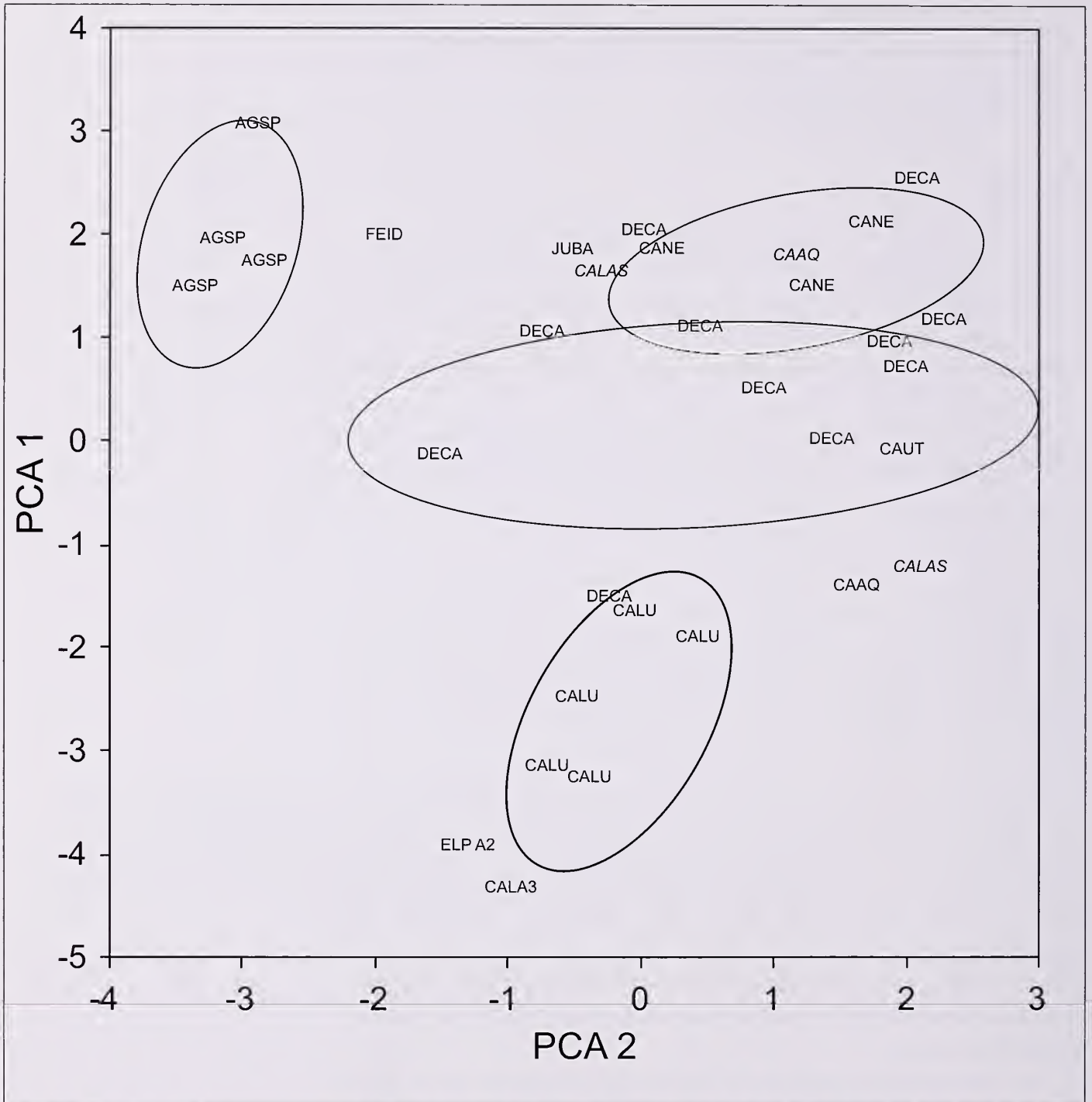


Figure 5—Plot of principal component scores for 32 meadows on the Umatilla National Forest. Labels are the plant associations according to Crowe and Clausnitzer (1997). Three outliers that did exhibit close association among similar meadow types are shown in italics. PCA1 and PCA2 are the first and second principal components.

displayed. The same is true for CALA3 (*C. lanuginosa* Michx.), another meadow type where the sample size was limited. In both cases, it is possible that the meadows contained significant cover of additional sedge species. Low PCA1 scores were associated with the CALU (*C. luzulina* Olney) meadows. This sedge is an obligate hydrophytic species, and the CALU meadows are located at high elevations and are very wet. All four CALU meadows formed a relatively tight cluster in the PCA plot (fig. 5).

Discussion

The elimination of two (June and August) of the five Landsat scenes owing to clouds most likely reduced the effectiveness of the methods used here. However, even with this reduced set of images, this analysis demonstrated the utility of within-year, multitemporal Landsat TM imagery for differentiating meadow samples based on the dominant sedge species. Most of the samples fell into logical clusters of meadows with similar plant association types. These results suggest that the tasseled-cap transformation was able to capture key differences among species of sedge. Although outliers were found in the results, they may well be from meadows that might be more aptly characterized as mixes of sedge species rather than dominated by a particular one. The results also suggest that the methods can be used to differentiate among upland grassland communities, although the sample of grasslands in the study was insufficient to evaluate this possibility.

Certain sedge species are excellent indicators of seasonal hydrological condition. They are very responsive to slight changes in water table over time and, therefore, are good features to use for identifying hydrologically degraded meadows (Crowe and Clausnitzer 1997). Being able to use remotely sensed data to detect the sedge species associated with specific hydrologic conditions could be invaluable for efficient mapping and monitoring of these sensitive areas.

As new meadows are located and added to the data set, it should be possible to characterize them based on their similarity to existing clusters. Given a larger sample and a validated reference data set, a supervised classification could be used for identifying and characterizing meadows over large areas. Owing to time and resource constraints, the effects of including or excluding TM scenes on meadow classification results were not explored, nor did this analysis consider additional principal components, use of the raw Landsat data, or other transformations. Given the promising results from the simple approach used here, it is likely that the classification/clustering process of the meadows could be improved.

The potential applications of this process fall into three general categories: classification, verification, and monitoring. First, in areas where meadow or

nonforest vegetation has not been classified, a relatively small number of training sites could be collected and used to classify meadows and grasslands. Vegetation typing could then be used to help prioritize fieldwork for identifying rare and endemic riparian plants, and for identifying hydrologically important meadows. Second, in areas where meadow inventories have been completed, the methods developed here could be used for verification or screening of plant association data for errors. Third, methods used here could aid in the identification of degraded meadows by monitoring changes in PCA scores, or similar measures, over time. For example, imagery of this study area from 5 and 10 years ago could be compared with the current imagery to identify and delineate areas where there has been a loss or gain of obligate wetland species of sedge or other plants.

The presence of specific indicator species in meadows can yield valuable information on meadow conditions in terms of seasonal trends in subsurface moisture and grazing pressure. A multitemporal approach was found to be especially effective in characterizing the seasonal phenology of meadow vegetation and in differentiating among meadows dominated by closely related sedge species. The ability to perform meadow characterizations over large areas provides an additional tool for monitoring of meadows over time and identifying those that meet criteria for restoration projects.

The methods described here also may be useful for screening large areas for infestation of invasive plants that have distinct vegetative and floral phenologies. For instance, sulfur cinquefoil (*Potentilla recta* L.) has a distinctive floral phase in late June that might be detectable with the methods described here.⁴ Another invasive, meadow hawkweed (*Hieracium caespitosum* Dumort.) remains green late in the growing season and may well have a unique spectral signature compared to surrounding vegetation.

⁴ Parks, C. 2003. Personal communication. Plant pathologist, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, OR 97850-3399.

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English Equivalents

1 meter (m) = 3.28 feet

1 hectare (ha) = 2.47 acres

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